CHAPTER 3

EPA/NSF ETV
EQUIPMENT VERIFICATION TESTING PLAN FOR ON-SITE GENERATION OF HALOGEN DISINFECTANTS FOR INACTIVATION OF MICROBIOLOGICAL CONTAMINANTS

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1.0 APPLICATION OF THIS VERIFICATION TESTING PLAN

This document is the ETV Testing Plan for evaluation of water treatment equipment utilizing on-site generation of halogen disinfectants used in drinking water treatment systems for small public or private water supplies. This Testing Plan is to be used as a guide in the development of the Product-Specific Test Plan (PSTP) for testing of microbiological inactivation equipment using on-site generation of halogen disinfectants, within the structure provided by the Protocol entitled "EPA/NSF ETV Protocol For Equipment Verification Testing For Inactivation Of Microbiological Contaminants: Requirements For All Studies".

Various types of treatment equipment employ on-site generation of halogen disinfectants to meet water treatment objectives such as microbiological inactivation and oxidation. This Equipment Verification Testing Plan is applicable only to treatment systems that rely on equipment for on-site generation of halogen disinfectants to effectively inactivate microorganisms in drinking water treatment systems. Systems may incorporate innovative techniques for generation of halogen disinfectants, such as the electrolysis of brine to produce chlorine and multiple oxidants.

In order to participate in this equipment verification process for microbiological inactivation via on-site generation of halogen disinfectants, the equipment Manufacturer shall employ the procedures and methods described in this test plan and in the referenced ETV Protocol as guidelines for the development of the PSTP. The Field Testing Organization (FTO) shall clearly specify in its PSTP the methods that shall be used for spiking of microorganisms, sampling of water streams and determination of microorganism viability, as well as any methods to be used for measurement of disinfectant concentrations in treated water streams. Methods for assessing the viability of cysts and oocysts are non-standard but may be used in verifying objectives that an on-site halogen generation system inactivates protozoan cysts and oocysts if the method has undergone peer review. Any non-standard method for assessing cyst and oocyst viability shall be correlated to animal infectivity.

2.0 INTRODUCTION

This ETV Testing Plan is applicable to any system that is used for on-site generation of halogen disinfectants for drinking water treatment applications, such as primary disinfection, residual disinfection, and process chemistry enhancement. This Testing Plan is also applicable to treatment systems that used in response to emergency scenarios. Typical systems in this category for on-site generation of halogen disinfectants may include but are not limited to: salt brine electrolysis generators, mixed oxidant systems, systems that include on-site generation of chlorine dioxide, systems providing iodination technologies, and other systems employing on-site generation of halogens. Based upon the goals of the Verification Testing Program, there are four primary aspects to the equipment evaluation process: 1) demonstration of equipment operation and generation capabilities; 2) measurement of halogen concentration and speciation; 3) inactivation of microbiological contaminants in feed waters to the system; and 4) measurement of the formation of disinfection by-products (DBPs) and other water quality parameters in treated waters.

To be applicable for this verification program, the on-site halogen generation systems must have the primary goal of halogen production for use in drinking water treatment applications. Additional goals of the on-site halogen generation systems may be to inactivate microbial

contaminants (primary disinfection), to provide a residual disinfectant in the distribution system (residual disinfection), to reduce formation of disinfection by-products (DBPs), or to provide oxidation of dissolved and particulate matter (organic or inorganic) in the source water.

On-site halogen generation systems that reduce the reliance on chlorine for disinfection hold promise for small utilities. Small on-site generators may be easier to operate than chlorine gas systems, and may provide effective oxidation of dissolved water constituents. In addition, the use of on-site generation systems such as salt brine electrolysis generators, mixed oxidant systems and chlorine dioxide generators may also allow for reduced formation of disinfection by-products. Further, on-site systems, such as iodine generators, may have applications in emergency situations.

3.0 GENERAL APPROACH

Testing of equipment covered by this Verification Testing Plan will be conducted by a NSF-qualified FTO that is selected by the equipment Manufacturer. The analytical work will be contracted with a laboratory that is certified, accredited or approved by the state, a third party organization (i.e., NSF) or the U.S. Environmental Protection Agency (EPA) for the appropriate water quality or microbiological parameters.

For this Verification Testing, the Manufacturer shall identify in a Statement of Performance Objectives the specific performance criteria to be verified and the specific operational conditions under which the verification testing shall be performed. There are several types of Statements of Performance Objectives that may be verified in this testing. Examples of Statements of Performance Objectives are included in Table 1.

Table 1.
Types of Statements of Performance Objectives for On-Site Halogen Generation Systems

Type of Statement of Performance Objectives	Example of Statement of Performance Objectives
Halogen Production	*"This system is capable of producing a halogen concentration of 1,000 mg/L (0.1%) as ClO_2 in the concentrated halogen stream at a generation system output of 80%."*
CT	*"This system is capable of producing a chlorine concentration of 10 mg/L for a 10-minute contact time that will meet or exceed EPA published CTs for 1.0 log_{10} inactivation of Giardia at a generation system output of 80% for a feed water flow of 100 gpm for a feed water with pH of 8.0 or less, turbidity of 20 NTU or less, organic carbon concentrations between 2.0 and 4.0 mg/L, alkalinity less than 150 mg/L as $CaCO_3$ and water temperatures greater than 5°C."*
CT (Comparative)	*"This system is capable of producing halogen concentrations that will meet EPA published CTs for 4-log_{10} inactivation of virus and 3- log_{10} inactivation of Giardia at a generation system output of 80% for a feed water flow of 100 gpm for a feed water with pH of 8.5 or less, turbidity of 20 NTU or less, organic carbon concentrations between 2.0 and 4.0 mg/L and alkalinity less than 150 mg/L as $CaCO_3$, while producing DBP concentrations 75% less than those produced by free chlorine at identical CTs."*
Microbial Inactivation	*"This system is capable of achieving 3-log_{10} inactivation of Giardia lamblia at a generation system output of 80% for a feed water flow of 100 gpm for a feed water with pH of 8.5 or less, turbidity of 20 NTU or less, organic carbon concentrations between 2.0 and 4.0 mg/L and alkalinity less than 150 mg/L as $CaCO_3$."*
Microbial Inactivation (Comparative)	*"This system is capable of achieving 3-log_{10} inactivation of Giardia lamblia at CTs 20% lower than EPA's published chlorine CTs. This level of Giardia lamblia inactivation will be achieved by the equipment at a generation system output of 80% for a feed water flow of 100 gpm for a feed water with pH of 8.5 or less, turbidity of 20 NTU or less, organic carbon concentrations between 2.0 and 4.0 mg/L and alkalinity less than 150 mg/L as $CaCO_3$."*

The tasks required to complete the Verification Testing depend on the type of Statement of Performance Objectives made by the Manufacturer. The following tasks are included in this Verification Testing program:

- Task 1: Equipment Operation and Disinfectant Production Capabilities
- Task 2: Microbiological Contaminant Inactivation (Optional)
- Task 3: Treated Water Quality
- Task 4: Data Management
- Task 5: Quality Assurance/Quality Control (QA/QC)

For each of the above-mentioned tasks and Statements of Performance Objectives, there are a number of different operational and system characteristics that would require evaluation during Verification Testing. Table 2 provides an overview of the equipment operational characteristics to be evaluated in tasks 1 through 3 of the Verification Testing Plan. Tasks 4 and 5 shall be performed for all Statements of Performance Objectives.

Table 2.
Summary of Equipment Operational Characteristics
To be Evaluated in Each Verification Testing Task

Type of Statement of Performance Objectives (See Table 1)	Equipment Operational Characteristic to be Evaluated	Task*
Halogen Production	1. Range of feed water flow rates	1
	2. Range of halogen concentrations produced under a variable range of percent generator output	1
	3. Speciation of halogens produced	1
	4. DBP formation	3
	5. Power consumption	1
	6. Characteristics and costs of initial constituent materials for halogen generation	1
	7. Waste stream characterization and range of waste stream flow rates	1
CT	Characteristics 1 through 7, and:	
	8. Hydraulic tracer testing	1
	9. Range of hydraulic residence times of feed waters (disinfectant contact times) through the system	1
Microbial Inactivation	Characteristics 1 through 9, and:	
	10. Microbial inactivation	2

*Note: Tasks 4 and 5 shall be performed for all Statements of Performance Objectives

4.0 OVERVIEW OF TASKS

The following section provides a brief overview of the recommended tasks that may be components of the Verification Testing Plan and PSTP for on-site generation of halogen disinfectants used in drinking water treatment systems for small public or private water supplies.

4.1 Task 1: Equipment Operation and Disinfectant Production Capabilities

The objective of this task is to operate the treatment equipment provided by the Manufacturer and to assess its ability to produce on-site generation of halogen disinfectants for microbial contaminant inactivation. The system performance shall be evaluated relative to the stated water quality goals and any other performance characteristics specified by the Manufacturer. For Verification Testing purposes, the equipment shall be operated for a minimum of one, one-month testing period for each operational condition for which verification is desired. It is recommended that Verification Testing be performed under the poorest conditions of feed water quality for which the Manufacturer wishes to make a Statement of Performance Objectives. The FTO must provide statements in the PSTP as to what would constitute the worst-case feed water quality for the specific on-site halogen generation system. Examples of such worst-case feed water quality may include cold temperatures and/or high concentrations of suspended solids, organic carbon or oxidizable materials. Additional one-month testing periods shall be performed for other feed

water qualities or other operating conditions for which the Manufacturer wishes to make a Statement of Performance Objectives.

For all types of Statements of Performance Objectives, the FTO shall evaluate the following operational parameters: range of flow rates for which system is designed, concentration of disinfectants generated by the system (under a range of operational conditions and a range of percent disinfectant output), the speciation of the disinfectants produced by the on-site generation system, and production of DBPs. For Statements of Performance Objectives based on CT or inactivation, the FTO shall also determine hydraulic retention times. For Statements of Performance Objectives based on inactivation, the FTO shall determine contact times between the disinfectant and microbiological contaminants. Inactivation of microbiological contaminants will be addressed in Task 2. Formation of DBPs and other water quality impacts in treated waters will be addressed in Task 3.

4.2 Task 2: Microbiological Contaminant Inactivation (Optional)

This task shall be performed if the Statement of Performance Objectives is based on inactivation. This task may be waived if the Statement of Performance Objectives is based only on halogen production or CT. The objective of this task is to measure the performance of the on-site halogen generation drinking water treatment equipment for inactivation of selected bacterial, viral or protozoan contaminants that may include: *Clostridium perfringens*, *Klebsiella*, *Pseudomonas aeruginosa* (if there high HPC counts are present in feed waters), MS2 bacteriophage, *Giardia lamblia*, and/or *Cryptosporidium parvum*.

4.3 Task 3: Treated Water Quality

The objective of this task is to evaluate the quality of treated water. Multiple water quality parameters will be monitored during each testing period. The mandatory water quality monitoring parameters for all testing periods shall include: pH, temperature, turbidity, disinfectant residual, hydrogen sulfide, alkalinity, total dissolved solids (TDS), ammonia nitrogen, total organic carbon (TOC), UV absorbance at 254 nm (UVA), true color, iron, manganese, chloride, bromide, sodium, total coliforms, and heterotrophic plate count (HPC) bacteria. Monitoring of free available chlorine (FAC) and total available chlorine (TAC) shall be required for all Verification Testing of on-site halogen generation systems, whether or not chlorine is considered the primary agent of inactivation. Formation of instantaneous and/or DBP formation testing of organic DBPs in the treated water shall also be monitored by the FTO, as applicable. Inorganic by-products of treatment with the on-site halogen generation system shall be monitored as applicable, including but not limited to chlorite, chlorate and bromate. Water quality produced shall be evaluated in relation to feed water quality and operational conditions.

4.4 Task 4: Data Management

The objective of this task is to establish an effective field protocol for data management at the field operations site and for data transmission between the FTO and NSF for data obtained during the Verification Testing. Prior to the beginning of field testing, the database design must be developed by the FTO and reviewed and approved by NSF. This will insure that the required data will be collected during the testing, and that it can be effectively transmitted to NSF for review.

4.5 Task 5: Quality Assurance/Quality Control (QA/QC)

An important aspect of Verification Testing is the protocol developed for quality assurance and quality control. The objective of this task is to assure accurate measurement of operational and water quality parameters during Verification Testing of the on-site halogen generation equipment. Prior to the beginning of field testing, a QA/QC plan must be developed which addresses all aspects of the testing process. Each water quality parameter and operational parameter must have appropriate QA and QC measures in place and documented. For example, the protocol for pH measurement should describe how the pH meter is calibrated (frequency, pH values), what adjustments are made, and provide a permanent record of all calibrations and maintenance for that instrument.

5.0 TESTING PERIODS

For Verification Testing purposes, the equipment shall be operated for a minimum of one, one-month testing period at each set of operational conditions and/or feed water qualities for which verification is desired (i.e., conditions of testing that will support the Statement of Performance Objectives). For example, separate one-month testing periods shall be performed for different operating conditions of the halogen generation equipment, such as different output levels of the halogen generator (e.g., separate one-month testing periods for 80%, 50% and 20% generator output). Examples of some of the different operational conditions that might be included as separate testing periods in the Verification Testing program are listed in Table 3.

Table 3.
Examples of Potential Operating Conditions for Verification Testing

Potential Operating Conditions	Required Testing Period	Required Tasks per Testing Period	Optional Tasks per Testing Period
80% generator output	one month	1, 3, 4, 5	2
50% generator output	one month	1, 3, 4, 5	2
20% generator output	one month	1, 3, 4, 5	2

It is recommended that one-month of Verification Testing shall be performed under the poorest feed water quality for which the Manufacturer wishes to verify the Statement of Performance Objectives. The FTO must provide statements in the PSTP as to what would constitute the worst-case feed water quality for the specific on-site halogen generation system. Examples of some of the different water quality conditions that might be included as separate testing periods in the Verification Testing program are listed in Table 4.

Table 4.
Examples of Potential Feed water Types for Evaluation in Distinct Testing Periods

Potential Testing Conditions	Required Testing Period	Required Tasks per Testing Period	Optional Task in Testing Period
Poor Water Quality	one-month	1, 3, 4, 5	2
Spring Run-Off Event	one-month	1, 3, 4, 5	2
Summer Algae Bloom	one-month	1, 3, 4, 5	2
Cold Temperature	one-month	1, 3, 4, 5	2
Untreated Surface Water	one-month	1, 3, 4, 5	2
Treated Surface Water	one-month	1, 3, 4, 5	2
Groundwater	one-month	1, 3, 4, 5	2
Groundwater Under the Influence	one-month	1, 3, 4, 5	2

Examples of poor feed water quality may include high concentrations of suspended solids, organic carbon or other materials that can exert an oxidant demand. These worst-case feed water quality characteristics may not occur simultaneously. For example, the Manufacturer may wish to conduct an additional one-month testing period during a spring run-off event in order to demonstrate equipment performance on a water quality characterized by elevated turbidity and organic material. The Manufacturer may wish to conduct testing in another one-month testing period during a summer algae bloom for demonstration of performance under conditions of elevated levels of organic material. Additionally, the Manufacturer may wish to conduct testing in a third one-month testing period during the coldest water temperatures of the winter.

The Manufacturer may also wish to demonstrate the Statement of Performance Objectives using water supplies from both surface water sources (treated and untreated) and groundwater sources (e.g., untreated and/or under the influence of surface water). In this case, the FTO must provide statements in the PSTP as to what constitutes the worst-case feed water quality for each supply and schedule the testing periods accordingly.

Prior to the initiation of Verification Testing, sufficient information shall be provided to illustrate the variations expected to occur in feed water quality for a typical annual cycle for the water source. Any pretreatment chemical additions that may impact the feed water to the on-site halogen generation system shall be fully described by the FTO in the PSTP. For example, any coagulant or other chemical additions shall be identified. Predicted effects on feed water turbidity, suspended solids and total organic carbon concentration shall also be discussed in the PSTP prepared by the FTO. Failure to adequately characterize the feed water could result in testing at a site later deemed inappropriate, so the initial characterization will be important to the success of the testing program.

The required tasks (Task 1 and Tasks 3 through 5) and optional task (Task 2) in the Verification Testing Plan are designed to be completed during each one-month testing period performed for the Verification Testing. One month is the minimum duration of each testing period; longer testing periods may be employed at the discretion of the Manufacturer or as necessary to complete the required (and optional, if applicable) tasks. The required one-month duration of each testing period does not include the time required for mobilization or start-up, nor does it include the time required to achieve steady-state operation.

6.0 TASK 1: EQUIPMENT OPERATION AND DISINFECTANT PRODUCTION CAPABILITIES

6.1 Introduction

During Task 1, the FTO shall evaluate equipment operations and determine the rates of feed water flow and halogen production concentration for which the on-site generation system is designed. The on-site halogen generation equipment shall be operated for Verification Testing purposes within the operational range presented in the Manufacturer's Statement of Performance Objectives, as described above in Section 3.0. Monitoring in Task 1 shall be focused on determination of the operational characteristics summarized above in Table 2, depending on the type of Statement of Performance Objectives made in the PSTP, or other factors applicable to the technology that provide effective treatment of the feed water. The FTO shall establish the testing conditions to be evaluated for Task 1 in the PSTP.

Before the initiation of Verification Testing in Task 1, the FTO on behalf of the Manufacturer shall make known the limitations of the equipment and any existing equipment incompatibilities with treatment processes or chemical additions. To this end, a listing shall be provided by the Manufacturer describing the potentially incompatible treatment processes or chemical additions (i.e., oxidants, coagulants, anti-scalants, chemicals for pH adjustment) that would adversely impact the equipment materials or the treatment process. In addition, the FTO shall report any incompatibilities between equipment and treatment processes or chemical additions that are observed during the course of the Verification Testing Program.

The FTO (with input from the equipment Manufacturer) may want to conduct preliminary studies in Task 1 to determine the range of operational capabilities during initial runs with the on-site halogen generation equipment. For Statements of Performance Objectives based on CT or microbial inactivation, the FTO shall describe in the PSTP the type of disinfectant contacting system that will be employed during Verification Testing of the on-site halogen generation system. The FTO shall also propose and fully describe in the PSTP the method of hydraulic tracer testing that will be performed to demonstrate flow conditions and residence duration (exposure time). Procedures for developing a tracer test methodology are described in the General Requirements section of the Protocol for Equipment Verification Testing of Microbiological Contaminant Inactivation.

This testing plan applies to halogen generation systems that are designed for either continuous flow or for intermittent flow through the generation equipment. If the Statement of Performance Objectives applies to intermittent flow applications, this should be specifically stated in the Statement of Performance Objectives and the work plan should include a designated shutdown period each day in which the on-site halogen generation equipment is turned off.

6.2 Objectives

The objectives of Task 1 are to determine the appropriate range for equipment operation and to determine the range of disinfectant concentrations (as well as speciation) generated under different conditions of percent system generation output. The performance of on-site halogen generation systems may be different for feed waters from different test sites or for the feed water from the same site during different seasonal water quality episodes. Therefore, it will be necessary to fully document the feed water conditions under which Verification Testing is

performed. Complete chemical, biological and physical characterization of the feed waters and treated waters produced by the system will be performed as part of Task 3. This task is intended to result in data that describe the operation of the equipment and data that can be used to develop cost estimates for operation of the equipment.

6.3 Work Plan

Mobilization and start-up of equipment shall be performed prior to the initiation of Task 1 testing. Furthermore, the on-site halogen generation system shall have achieved a condition of steady-state operation before the start of Task 1 testing. The FTO shall clearly describe in the PSTP the protocol for start-up of the on-site halogen generation system, as well as operations and maintenance issues that may arise during mobilization and start-up.

During each day of Verification Testing in Task 1 (minimum one-month testing period at one set of operational conditions and/or one set of water quality characteristics), treatment equipment operating parameters for the on-site halogen generation will be monitored and operating data will be recorded. Operating parameters for monitoring shall include: rate of feed water and treated water flow; generated halogen concentration and speciation (dilution of concentrated halogen stream may be required); rate and quality of feed stock (i.e., salt) consumption, and other equipment characteristics as specified for measurement by the FTO in the PSTP. In addition, the aggregate horsepower of all motors and mechanical efficiencies of all motors/devices supplied with the equipment shall be determined and used to develop an estimate of the maximum power requirements and routine power consumption during operation. A summary of the operational parameters to be recorded during Task 1 and the minimum frequency of monitoring is presented in Table 5. The FTO shall provide the necessary methods information for monitoring of the operational parameters presented in Table 5. Additional monitoring of feed water chemistry shall be performed during Verification Testing, as described below in Task 3 (Section 8.0).

If any waste streams are generated by the on-site halogen generation system, these streams must be fully characterized during Task 1 testing. The FTO shall fully describe and provide general characterization of the waste streams that are generated by the on-site halogen generation system in the PSTP, including pH, total dissolved solids (TDS), alkalinity, disinfectant residual, and temperature. In the case that water softening of the feedwater is required prior to halogenation, the characteristics of the waste streams produced by the water softener shall also be described. The FTO shall also discuss the applicable potential waste stream disposal issues in the PSTP, including disposal to the sewer or receiving water.

Table 5.
Task 1 - Required Minimum Operating Data for On-Site Halogen Generation Systems

Operational Parameter	Action, Monitoring Frequency
Feed water flow rate	Check and record twice daily. Adjust when 10% above or below target. Record both before and after adjustment.
Rate of feed stock consumption	Check and record consumption twice daily. Adjust when 10% above or below target. (Quality of feed stock required by equipment shall also be recorded.)
Halogen concentration and speciation (at each set of operational conditions)	Sample the following and record twice daily: 1. Concentrated halogen stream (generator product) 2. Halogen-treated water at disinfection contactor influent (if applicable) 3. Halogen-treated water at disinfection contactor effluent (if applicable)
Horsepower and efficiency of motors, and consumed amperage for on-site generation (at each set of operational conditions)	Provide record of current draw to motors on cumulative basis. Provide information on start-up amperage and horsepower requirements.
Waste stream composition (Testing recommended for each batch of constituent chemicals)	Sample once each one-month testing period for: pH, NaOH, TDS, heavy metal scan (only those technologies producing definable waste). Water softeners may require monitoring of additional parameters.
Waste stream flow rate	Check and record waste flow streams (if applicable) twice daily.
For Statements of Performance Objectives based on CT or microbial inactivation: Hydraulic detention time in disinfectant contacting system (at selected flow rate)	Provide correlation to measured value on daily basis.

6.4 Schedule

During Verification Testing, water treatment equipment shall be operated continuously for a minimum of one month at one set of operational conditions (e.g., percent generator output – Table 3) and/or one feed water quality (examples given Table 4). Interruptions in operation may be allowed during the one-month testing period as needed for system maintenance. Necessary details of the system shutdown procedure shall be specified by the FTO in the PSTP.

6.5 Evaluation Criteria

- General operational performance
  - ⇒ Temporal profile of feed water flow rate over each one-month testing period. One temporal profile graph (at daily resolution) shall be provided for each set of operational conditions and/or water qualities evaluated during Verification Testing.

⇒ Temporal profile of waste stream flow rate measured during each one-month testing period.

⇒ Table of disinfectant concentrations generated for each disinfectant species in the halogenated water and treated water streams during each one-month testing period.

- Rate of consumption of feed material for halogen generation and for feedwater conditioning. Quality of feedstock material required for halogen generation shall also be reported.
- Power consumption
  ⇒ Table of horsepower requirements, motor efficiency and consumed amperage for the testing period(s), as measured for each set of operational conditions.
- Waste stream characterization
  ⇒ Table of waste stream quality parameters measured during each one-month testing period.
- Contact time (only for Statements of Performance Objectives based on CT or microbial inactivation)
  ⇒ Table of calculated or estimated hydraulic detention time in disinfectant contacting system for each set of operational conditions evaluated during the testing period(s).

7.0 TASK 2: MICROBIOLOGICAL CONTAMINANT INACTIVATION (OPTIONAL)

7.1 Introduction

If the Statement of Performance Objectives is based on microbial inactivation, the effectiveness of the on-site generation equipment for inactivation of microorganisms such as bacteria, viruses, or protozoa (or a combination thereof) introduced in the feed water to the system will be evaluated in this task. The measurement of inactivation for this study will be based upon a comparison of the percent of viable organisms in the feed water stream and the percent of viable organisms in the halogen-treated water stream at the disinfection contactor effluent. In the case that the FTO can demonstrate that the feed waters contain a naturally occurring and consistent concentration of microorganisms approved by this inactivation test plan that is sufficient to demonstrate the manufacturer's Statement of Performance Objectives, no spiking of organisms will be necessary for the inactivation experiments.

7.2 Objectives

The objective of this task is to characterize the on-site halogen generation technology in terms of efficacy for inactivation of selected microbiological contaminants. Microorganisms for inactivation testing will be selected by the FTO and specifically identified in the PSTP.

7.3 Work Plan

If the Manufacturer’s Statement of Performance Objectives is based on microbial inactivation, the FTO shall identify the microbiological contaminant inactivation capabilities in the Statement of Performance Objectives provided in the PSTP. In the Statement of Performance Objectives, the Manufacturer shall identify the specific microbiological contaminants to be monitored during equipment testing and the specific operational conditions under which inactivation testing shall be performed. The Statement of Performance Objectives prepared by the FTO on behalf of the Manufacturer shall also indicate the range of water quality under which the equipment can be

challenged while successfully treating the feed water. Examples of satisfactory Statements of Performance Objectives based on microbial inactivation were provided in Table 1.

7.3.1 Organisms Employed for Inactivation Experiments

The FTO on behalf of the Manufacturer shall specify which organisms shall be employed in Verification Testing for demonstration of the inactivation efficacy of the on-site halogen generation system. Examples of organisms for potential use in this task are listed below in Table 6. These species represent microorganisms of particular interest and concern to the drinking water industry, and represent a range of resistance to inactivation methods. The specific batches of microorganisms used must be shown to be viable by the laboratory involved in the analytical aspects of the testing. The FTO shall specify in their PSTP, which of the approved organisms will be employed for Verification Testing. The FTO shall also specify the specific methods that shall be used for analysis of the count and the viability of the test organisms.

Table 6.
Example Microorganisms for Task 2 Inactivation Experiments

Type of Spiking Organism	Example Microorganisms for Inactivation Experiments
Bacteria	*Clostridium perfringens* *Klebsiella* *Pseudomonas aeruginosa* (if high HPC counts are present) Total Coliform Bacteria
Virus	MS2 Bacteriophage Enteric virus species
Protozoan (oo)cysts	*Giardia lamblia* *Cryptosporidium parvum*

Microbial inactivation experiments with the on-site generation system shall be performed as three replicate studies done consecutively at one set of selected operational conditions and/or a range of influent water qualities, as required in Task 1. Microbiological inactivation experiments may be conducted during the minimum one-month Verification Testing period that is required for a single set of operating conditions and/or influent water quality in Task 1. Only one process control test shall be performed in which the on-site halogen generation system is turned off. The FTO shall fully describe the spiking and sampling methods to be used during the microbial inactivation testing in Task 2. A description of some possible spiking and sampling methods is provided below in the Analytical Methods portion of this Section 7.0.

7.4 Analytical Methods

7.4.1 Spiking Protocols

The total number of each type of test organism required for spiking will depend on the reactor volume, the water flow rate, and the desired steady-state concentration of microbiological contaminants in the reactor. The total number of organisms required to provide these steady-state microbiological populations will depend on the overall volume

of the disinfection contactor, the detection limits of the sampling and analytical methods and the duration of experiments. For all organisms, the laboratory(ies) supplying the organisms and performing the viability studies shall be experienced in challenge testing and be able to predict initial dosages required to overcome any inherent experimental losses. The FTO shall fully describe in the PSTP the spiking methodology to be employed during the microbiological inactivation testing. An example of a spiking protocol for microbiological inactivation studies is provided below.

The feed water stream to the on-site halogen generation test unit will be plumbed with a check-valve to prevent back-flow of waters spiked with concentrations of microbiological contaminants. Consistent dosing of the spiking stock suspension will be controlled by means of a metering pump (diaphragm or peristaltic or equivalent) via siliconized or Teflon tubing. The pump shall be capable of fluid injection into the pressurized system feed line for the duration of the test, at a measurable and verifiable rate such that the dosing of the spiking stock suspension is consistent throughout the duration of the test run. Once appropriate flow has been initiated through the test system, the test unit must be demonstrated to operate in a steady-state condition. The spiking shall continue for a period of time that allows a minimum of three retention time-equivalents through the on-site generation and contacting system (as determined by tracer tests or as defined by system functions) prior to sample collection. During the course of the experiment, monitoring of the system flow rate and spike injection rate shall be performed and adjustments made to maintain test design.

7.4.2 Sample Collection

7.4.2.1 Test Stream Sampling. Sample ports shall be provided for the feed water stream (spiked with concentrations of microbiological contaminants) and the halogen-treated water stream at the contactor effluent. The FTO shall specify the specific ways in which sample collection is performed according to the organisms that will be used for the proposed microbiological inactivation experiments. Examples of potential sample collection methods for bacterial, viral and protozoan organisms are provided below. The methods described, or any other peer-reviewed method may be used for verification testing. The FTO shall propose in the PSTP the specific methods that are to be used for viability assessment of the selected microorganisms (See Section 7.5 below).

For bacterial and/or viral seeding experiments, methods for organism spiking and sample collection shall be consistent with a selected peer-reviewed method. The frequency and number of samples collected for each sampling point will be determined by the length of the test run and shall be specified by the FTO in the PSTP. The volume of each halogen-treated water sample from the disinfection contactor effluent will depend on the concentrations of test organisms spiked, and the requirements of the analytical laboratory.

For protozoan spiking experiments, EPA Method 1622 or any other method that has been evaluated through the peer-reviewed process (e.g., Nieminski and Ongerth, 1995) may be followed for sample collection from the spiked water streams. The sample collection system shall be plumbed to allow installation of housings and filters for capture of sufficient flow for microbiological analysis. The FTO shall provide an indication of the recovery efficiency achievable under the sample collection method selected for use during protozoa seeding studies. The specific capture filter recovery system shall be fully

described in the PSTP by the FTO. In addition, the PSTP shall include a plan of study for verification testing with a minimum of three standard recovery efficiency tests from the microbiological laboratory.

7.4.2.2 Post-Test Sample Handling. The FTO shall take steps to sanitize the system following microbial spiking experiments to inactivate any organisms remaining in the system. Depending on the unit (design and materials), sanitization may be done using steam or hot water (80°C for 10 min) or other acceptable disinfectant. The FTO shall specify in the QA/QC plan of the PSTP how this sanitization procedure is to be done to ensure inactivation of live organisms and subsequent removal of inactivated organisms from the unit. Biosafety concerns for humans and the environment that are associated with the disinfection of live organisms shall be outlined in the Safety Plan that is developed as part of the QA/QC plan in the PSTP. (Refer to section 10.5 of this test plan for more detail on the Health and Safety Measures to be detailed in the QA/QC Safety Plan.)

7.4.2.3 Process Control. A control round of testing shall also be carried out identical to the procedure identified by the FTO in the PSTP, with the on-site halogen generation system turned off. The purpose of this testing is to evaluate any cumulative effects of the equipment stream, spiking and sampling processes, and sample handling on organism viability. This testing shall not occur until elimination of sanitizing agents and inactivated target organisms, whose presence could affect the inactivation capabilities of the unit. The process control samples should show minimal inactivation of the target organism(s) relative to the trip control sample. If significant inactivation of the process control sample is measured in control testing, some aspect of the process other than on-site halogen generation system may have contributed to inactivation of the test organisms. Under such a scenario, re-testing of the on-site halogen generation system for microbiological inactivation would be required.

7.4.2.4 Trip Control. For tests utilizing spike challenges, a replicate or sub-sample of the spike dose shall accompany the actual spike dose from the analytical laboratory, including all preliminary processes of dose preparation pre-enumeration, shipping, and preparation for spiking, through return to the laboratory for enumeration and viability baseline assessment. The trip control samples should show minimal inactivation of the target organism(s). Significant inactivation of the trip control sample would indicate that some aspect of the handling, from preparation to testing, contributed to inactivation of the test organism(s). Evidence of greater than 90% inactivation of trip control samples will require re-testing.

7.4.2.5 Comparison Control. If the Statement of Performance Objectives involves comparison of microbial inactivation by the on-site halogen generation system to microbial inactivation by another disinfectant (i.e., chlorine), then a control experiment shall be conducted using the comparison disinfectant. In this experiment, all spiking, contacting, sampling and analysis must be identical to that employed for the inactivation testing with the on-site halogen generation system, with the exception that free chlorine shall be used to meet CT rather than the halogens generated on site.

7.5 Microbiological Viability Analysis

Methods for assessing the viability of the selected bacteria and viruses (see Table 6) shall be specified by a laboratory that is certified, accredited or approved by the state, a third party organization (i.e., NSF) or the EPA for the appropriate microbial analyses. Selected viability methods shall be specified by the FTO in the PSTP.

Methods for assessing the viability of cysts and oocysts are non-standard but may be used in verifying objectives that an on-site halogen generation system inactivates protozoan cysts and oocysts if the method has undergone peer review. A summary and comparison of viability methods is presented in research completed by the following researchers: Korich et al. (1993), Nieminski and Ongerth (1995), Slifko et al. (1997) and others (see Section 12.0 References in this Test Plan). Interim, non-standard methods for assessing the viability of cyst and oocyst (e.g., excystation, DAPI/PI) may be used for verification of inactivation after exposure to halogen disinfectants. However, any interim organism viability method is subject to review by experts of cyst and oocyst viability and subsequent method change. Any non-standard method for assessing cyst and oocyst viability shall be correlated to animal infectivity.

7.6 Evaluation Criteria and Minimum Reporting Requirements

- Concentrations of microbiological contaminants in the feed water and halogen-treated water at the disinfection contactor effluent
  - ⇒ Table of feed water and treated water concentrations of the NSF-approved spiked microorganisms (Table 6) for challenge experiments (three replicate runs), process control experiment, and comparison control experiment (if applicable)
  - ⇒ Trip control results
  - ⇒ Bar graph of $\log_{10}$ inactivation results for three replicate test runs and all control test runs
  - ⇒ The variability of the results from microbial inactivation tests should be presented with the bar graphs as 95% confidence intervals.

8.0 TASK 3: TREATED WATER QUALITY

8.1 Introduction

Water quality data shall be collected for the feed water and halogen-treated water as shown in the sampling schedule in Table 7. These data shall be collected during the equipment operation test runs of Task 1 and the microbiological contaminant inactivation test runs of Task 2 (if applicable). No additional test runs need to be performed for Task 3, other than those performed for Tasks 1 and 2.

8.2 Experimental Objectives

The objective of this task is to assess the impact on water quality of treatment with the on-site halogen generation system. Specific water quality analyses and sampling frequencies are detailed in Table 7.

8.3 Work Plan

A list of the minimum number of water quality parameters is provided in Table 7 for monitoring of the feed water, concentrated halogen stream, and halogen-treated water at the disinfection contactor influent and effluent during Equipment Verification Testing. The actual water quality parameters selected for testing and monitoring shall be stipulated by the FTO in the PSTP.

Table 7.
Water Quality Sampling Schedule (Minimum Required for Each Testing Period)

Parameter	Sampling Frequency	Test Stream to be Sampled	Standard Method	EPA Method
On-Site Analyses				
pH	1/Day	Feed, Treated[1], Waste	4500 H+	150.1/ 150.2
Temperature	1/Day	Feed, Treated, Waste	2550 B	
Turbidity	1/Day	Feed, Treated	2130 B	180.1
Disinfectant Residual: Chlorine (FAC, TAC) Iodine Chlorine Dioxide Bromine	2/Day	Feed[2], Concentrated Halogen Stream[3], Halogen-Treated Water at Contactor Influent[4] and Effluent[1], Waste	 4500-Cl F[5] 4500-I B[5] 4500-ClO_2 D[5]	 300.0 300.0
Hydrogen sulfide	1/Day	Feed	4500-S^{2-}	
Laboratory Analyses				
Alkalinity	1/Week	Feed, Treated, Waste	2320 B	
TDS	1/Testing Period	Feed, Treated, Waste	2540 C	
Ammonia Nitrogen	1/Week	Feed, Treated	4500-NH_3 G	
TOC	1/Testing Period	Feed, Treated	5310 C	
UVA	1/Week	Feed, Treated	5910 B	
True Color	1/Week	Feed, Treated	2120 B	
Iron	1/Testing Period	Feed, Treated	3500-Fe C	200.7/ 200.8/ 200.9
Manganese	1/Testing Period	Feed, Treated	3500-Mn C	200.7/ 200.8/ 200.9
Chloride	1/Testing Period	Feed, Treated	4500-Cl^- F	300.0
Bromide	1/Testing Period	Feed, Treated	4500-Br^- C	300.0
Sodium	1/Testing Period	Feed, Treated	3500-Na B	200.7
Total Coliform Bacteria	5/Week	Feed, Treated	9221 / 9222 / 9223	
HPC Bacteria	5/Week	Feed, Treated	9215 B	
TTHMs	1/Testing Period	Feed[2], Treated		524.2
HAAs	1/Testing Period	Feed[2], Treated		552.1

Table 7. (continued)
Water Quality Sampling Schedule (Minimum Required for Each Testing Period)

Parameter	Sampling Frequency	Test Stream to be Sampled	Standard Method	EPA Method
Optional DBPs[6]:				
Haloacetonitriles	1/Testing Period	Feed[2], Treated		551
(HANs)	1/Testing Period	Feed[2], Treated		551
Chloropicrin	1/Testing Period	Feed[2], Treated		551
Chloral Hydrate	1/Testing Period	Feed[2], Treated		524.2
Cyanogen Chloride				
Chlorite, Chlorate (if applicable)	1/Testing Period	Feed[2], Treated		300.0 B
Bromate (if applicable)	1/Testing Period	Feed[2], Treated		300.0 B
DBP Formation Testing[7]				
TTHMs	1/Testing Period	Treated		524.2
HAAs	1/Testing Period	Treated		552.1
Optional DBPs[6]:				
HANs	1/Testing Period	Treated		551
Chloropicrin	1/Testing Period	Treated		551
Chloral Hydrate	1/Testing Period	Treated		551
Cyanogen Chloride	1/Testing Period	Treated		524.2
Bromate (if applicable)	1/Testing Period	Treated		300.0 B
Chlorite, Chlorate (if applicable)	1/Testing Period	Treated		300.0 B

[1] For purposes of Table 7, "treated" water indicates the halogen-treated water at the disinfection contactor effluent. If the equipment being tested does not include a disinfection contactor (i.e., includes only feed water and concentrated halogen stream sampling points), then only the feed water sample shall be collected.

[2] Feed water sampling for these parameters shall be performed once during the Verification Testing to verify that no addition of disinfectants or oxidants and no formation of DBPs occurs upstream of the feed water sampling point.

[3] The "concentrated halogen stream" is the generator product stream.

[4] The "halogen-treated water at contactor influent" indicates the feed water to the equipment immediately after dosing with the concentrated halogen stream.

[5] The stated Standard Method shall be used if the halogen generator produces only one of the listed disinfectants (e.g., chlorine) and no other disinfectant. If the halogen generator produces more than one of the listed disinfectants, or if the halogen generator produces bromine, then the method described in White (1992) and Palin (1974) shall be used for disinfectant residual measurement.

[6] Optional DBPs shall be measured if applicable.

[7] DBP formation testing shall be conducted if on-site halogen generation equipment is used to provide both primary disinfection and residual disinfection. Conditions for DBP formation testing preparation shall follow the UFC proposed in the Information Collection Rule (see section 8.4.4 of this test plan).

If the on-site halogen generation system is used only for primary disinfection, with residual disinfection provided by another process, then sampling for organic (Total Trihalomethanes (TTHMs), haloacetic acids (HAAs) and optional DBPs) and inorganic (bromate, chlorite, chlorate) DBPs shall be performed on an instantaneous basis after the specified disinfection contact time. Both instantaneous sampling and simulated distribution system testing for organic and inorganic DBPs shall be performed if the on-site halogen generation system is used for both primary disinfection and residual disinfection. Water samples collected for DBP analysis should be collected simultaneously with samples collected for other analyses such as pH, alkalinity, TOC, UVA, turbidity, ammonia, and other pertinent water quality parameters.

Many of the water quality parameters described in this task shall be measured on-site by the FTO. Analysis of the remaining water quality parameters shall be performed by a laboratory that is certified, accredited or approved by the state, a third party organization (i.e., NSF) or the EPA for the appropriate water quality parameters. The methods to be used for measurement of all water quality parameters in the field and in the off-site analytical laboratory are specified in Table 7 and are described in detail in Task 5, Quality Assurance/Quality Control (QA/QC). Where appropriate, the Standard Methods reference numbers and EPA method numbers for water quality parameters are provided in Table 7 for both the field and laboratory analytical procedures.

For the case of off-site shipment, the samples shall be collected in appropriate containers (containing preservatives as applicable) prepared by the off-site analytical laboratory. These samples shall be preserved, stored, shipped and analyzed in accordance with appropriate procedures and holding times, as specified by the analytical laboratory. Samples shall be shipped to a laboratory that is certified, accredited or approved by the state, a third party organization (i.e., NSF) or the EPA. Original field sheets and chain-of-custody forms shall accompany all samples shipped to the off-site analytical laboratory. Copies of field sheets and chain-of-custody forms for all samples shall be provided to NSF.

8.4 Analytical Schedule

8.4.1 Characterization of Feed Water, Concentrated Halogen Stream and Halogen-Treated Water at the Disinfection Contactor Influent and Effluent.

The water quality characteristics of the feed water, the concentrated halogen stream and the halogen-treated waters at the influent and effluent to the disinfection contactor shall be characterized by measurement of the parameters listed in Table 7. Sampling shall be performed during steady-state operation of the on-site halogen generation equipment in Task 1 and Task 2 (if applicable).

8.4.2 Water Quality Sample Collection

Water quality data for Task 3 will be collected at regular intervals during test runs conducted for Tasks 1 and 2, as indicated by the sampling frequency in Table 7. No additional test runs shall be required for Task 3 other than those already described in Tasks 1 and 2. The minimum monitoring frequency for the required water quality parameters is provided in Table 7. At the discretion of the Manufacturer and the designated FTO, the water quality sampling program may be expanded to include a

greater number of water quality parameters and to require more frequent sampling. Sample collection frequency and protocol shall be defined by the FTO in the PSTP.

8.4.3 Feed Water Quality Limitations

The characteristics of feed water encountered during each testing period shall be explicitly stated in reporting the data from Tasks 1 and 2. Accurate reporting of such feed water characteristics as turbidity, temperature, pH, ammonia nitrogen and total organic carbon is critical for the Verification Testing, as these parameters can substantially influence the disinfection performance of the on-site halogen generation equipment.

8.4.4 Disinfection By-Product Formation Testing

DBP formation testing shall be performed if the on-site halogen generation equipment is used for residual disinfection in addition to primary disinfection. DBP formation testing shall be performed on the treated water once each testing period (at a minimum) during steady-state operation of the on-site halogen generation equipment for Task 1 or Task 2. DBP formation testing will be used to estimate by-product formation in the distribution system, including TTHMs, the six measured HAA compounds, and (if applicable) HANs, chloropicrin, chloral hydrate, cyanogen chloride, bromate, chlorite and chlorate.

If no additional dosing of halogens is used for residual disinfection subsequent to primary disinfection, the DBP formation testing method shall be performed by collecting a sample of the halogen-treated water at the disinfection contactor effluent and holding the sample in the dark at the uniform formation conditions (UFC) specified in the Information Collection Rule (ICR) Manual for Bench- and Pilot-Scale Treatment Studies. If additional dosing of the halogens is used for residual disinfection subsequent to primary disinfection, the DBP formation testing method shall be performed by collecting a sample of the halogen-treated water at the disinfection contactor effluent, spiking it with an additional dose of disinfectant, and holding the sample in the dark at the UFC. (Refer to the DBP formation testing protocol in Task 5, QA/QC, of this Verification Testing Plan for further details.)

The following UFC will be used for DBP formation testing:

- Incubation period of 24 ± 1 hours
- Incubation temperature of 20 ± 1.0°C
- Buffered pH of 8.0 ± 0.2
- 24-hour chlorine residual of 1.0 ± 0.4 mg/L.

8.4.5 Comparison DBP Testing

If the Statement of Performance Objectives involves comparison of DBP formation by the on-site halogen generation system to DBP formation by another disinfectant (i.e., chlorine), then comparison DBP testing (and DBP formation testing, if applicable) shall be conducted using the comparison disinfectant. For these comparisons, identical procedures for sampling, testing and analysis shall be performed for the DBP sampling with the on-site halogen generation system and alternative disinfectants.

8.5 Evaluation Criteria and Minimum Reporting Requirements

In the items below, "treated water" refers to the halogen-treated water sampled at the disinfection contactor effluent.

- General water quality
  - ⇒ Table of daily feed water and treated water levels of pH, temperature and turbidity during each testing period
  - ⇒ Table of weekly feed water and treated water levels of alkalinity and ammonia nitrogen during each testing period
  - ⇒ Table of feed water and treated water levels of TDS, iron, manganese, chloride, bromide and sodium during each testing period
  - ⇒ Table of twice daily disinfectant residuals during each testing period
- Organic water quality
  - ⇒ Table of weekly feed water and treated water levels of UVA and true color during each testing period
  - ⇒ Table of feed water and treated water levels of TOC during each testing period
- DBPs
  - ⇒ Table of instantaneous, and DBP formation testing if applicable (for treated water only), feed water (one sample) and treated water concentrations of TTHMs and HAAs monitored during each testing period, and other optional DBPs, such as HANs, chloropicrin, chloral hydrate and cyanogen chloride (if applicable)
  - ⇒ Table of instantaneous, and DBP formation testing if applicable (for treated water only), feed water (one sample) and treated water concentrations of bromate, chlorite and chlorate (if applicable) during each testing period
  - ⇒ If applicable, table comparing instantaneous (and DBP formation testing, if applicable) DBP concentrations of TTHMs and HAAs, and if applicable, other DBPs (e.g., HANs, chloropicrin, chloral hydrate and cyanogen chloride) produced in the treated water by the on-site halogen generation system and a comparison disinfectant (i.e., chlorine)
- Indigenous bacteria (Total Coliform and HPC)
  - ⇒ Table of feed water and treated water levels of Total Coliform bacteria (TC) and HPC bacteria during each testing period
  - ⇒ Table of TC and HPC $\log_{10}$ inactivation during each testing period

9.0 TASK 4: DATA MANAGEMENT

9.1 Introduction

The data management system used in the Verification Testing shall involve the use of computer spreadsheet software and manual (or on-line) recording of operational parameters for the on-site halogen generation equipment on a daily basis.

9.2 Experimental Objectives

The objectives of this task are: 1) to establish a viable structure for the recording and transmission of field testing data such that the FTO provides sufficient and reliable data for

verification purposes, and 2) to develop a statistical analysis of the data, as described in the "EPA/NSF ETV Protocol For Equipment Verification Testing For Inactivation Of Microbiological Contaminants: Requirements For All Studies".

9.3 Work Plan

The following protocol has been developed for data handling and data verification by the FTO. Where possible, a Supervisory Control and Data Acquisition (SCADA) system should be used for automatic entry of testing data into computer databases. Specific parcels of the computer databases for operational and water quality parameters should then be downloaded by manual importation into Excel (or similar spreadsheet software) as a comma-delimited file. These specific database parcels shall be identified based upon discrete time spans and monitoring parameters. In spreadsheet form, the data shall be manipulated into a convenient framework to allow analysis of water treatment equipment operation. Back-up of the computer databases to diskette should be performed following each testing period at a minimum. When SCADA systems are not available, direct instrument feed to data loggers and laptop computers shall be used when appropriate.

For parameters for which electronic data acquisition is not possible, field testing operators shall record data and calculations by hand in laboratory notebooks. Daily measurements shall be recorded on specially-prepared data log sheets as appropriate. Each notebook must be permanently bound with consecutively numbered pages. Each notebook must indicate the starting and ending dates that apply to entries in the logbook. All pages shall have appropriate headings to avoid entry omissions. All logbook entries must be made in black water-insoluble ink. All corrections in any notebook shall be made by placing one line through the erroneous information. Products such as "correction fluids" are never to be utilized for making corrections to notebook entries. Operating logs shall include a description of the water treatment equipment (description of test runs, names of visitors, description of any problems or issues, etc.); such descriptions shall be provided in addition to experimental calculations and other items. The original notebooks shall be stored on site. This protocol will not only ease referencing the original data, but offer protection of the original record of results.

The database for the project shall be set up in the form of custom-designed spreadsheets. The spreadsheets shall be capable of storing and manipulating each monitored water quality and operational parameter from each task, each sampling location, and each sampling time. All data from the laboratory notebooks and data log sheets shall be entered into the appropriate spreadsheets. Data entry shall be conducted on site by the designated field testing operators. All recorded calculations shall also be checked at this time. Following data entry, the spreadsheet shall be printed out and the print-out shall be checked against the handwritten data sheet. Any corrections shall be noted on the hard-copies and corrected on the screen, and then a corrected version of the spreadsheet shall be printed out. Each step of the verification process shall be initialed by the field testing operator or engineer performing the entry or verification step.

Each experiment (e.g., each test run) shall be assigned a run number that shall then be tied to the data from that experiment through each step of data entry and analysis. As samples are collected and sent to the chosen laboratory(ies), the data shall be tracked by use of the same system of run numbers. The FTO may send samples to a laboratory that is certified, accredited or approved by the state, a third party organization (i.e., NSF) or the EPA for analysis of water quality parameters. Data from the outside laboratories shall be received and reviewed by the field

testing operator. These data shall be entered into the data spreadsheets, corrected, and verified in the same manner as the field data.

9.4 Statistical Analysis

Water quality developed from grab samples collected during test runs according to the Water Quality Sampling Schedule (Table 7) in Task 3 shall be analyzed for statistical uncertainty. For example, the FTO shall calculate the mean values, standard deviations and 95% confidence intervals for grab sample data obtained during the Verification Testing as described in the "EPA/NSF ETV Protocol For Equipment Verification Testing For Inactivation Of Microbiological Contaminants: Requirements For All Studies" (Chapter 1). The mean values with 95% confidence intervals can then be used to compare the water quality results from tests conducted under different conditions of equipment operation or feed water quality. For comparisons between data from more than two testing periods, construction of an analysis of variance (ANOVA) table may be helpful in determining the statistical significance of differences between operational, microbial inactivation and treated water quality results. Statistical analysis such as that described above could be carried out for water quality data obtained under a large variety of testing conditions. The statistics developed will be helpful in demonstrating the degree of reliability with which water treatment equipment can attain quality goals.

10.0 TASK 5: QUALITY ASSURANCE/QUALITY CONTROL

10.1 Introduction

Quality assurance and quality control (QA/QC) of the operation of the on-site halogen generation equipment and the measured water quality parameters shall be maintained during the Verification Testing program.

10.2 Experimental Objectives

The objective of this task is to maintain strict QA/QC methods and procedures during testing. When specific items of equipment or instruments are used, the objective is to maintain the operation of the equipment or instructions within the ranges specified by the Manufacturer or by *Standard Methods*. Maintenance of strict QA/QC procedures is important in that if a question arises when analyzing or interpreting data collected for a given experiment, it will be possible to verify exact conditions at the time of testing.

10.3 Work Plan

Equipment flow rates and associated signals shall be documented and recorded on a routine basis. A routine daily walk-through during testing shall be established to verify that each piece of equipment or instrumentation is operating properly. In-line monitoring equipment such as flow meters shall be checked to verify that the read-out matches with the actual measurement (i.e., flow rate) and that the signal being recorded is correct. The items listed below are in addition to any specified checks outlined in the analytical methods.

10.3.1 Daily QA/QC Verifications

These QA/QC verifications shall be conducted daily during testing:

- Chemical feed pump flow rates (verified volumetrically over a specific time period)
- Flow rates to in-line analytical equipment (e.g., pH meter, turbidimeter), if any (verified volumetrically over a specific time period)
- In-line turbidimeter readings checked against a properly calibrated bench-top model.

10.3.2 QA/QC Verifications Performed Every Two Weeks

These verifications shall be conducted every two weeks:

- In-line flow meters/rotameters (clean equipment to remove any debris or biological buildup and verify flow volumetrically to avoid erroneous readings).
- In-line turbidimeters, if any, (clean out reservoirs and re-calibrate, if employed)

10.3.3 QA/QC Verifications To Be Performed For Each Testing Period

This verification shall be conducted before each testing period begins:

- Tubing (verify good condition of all tubing and connections; replace if necessary)

10.4 Analytical Methods and Sample Collection

The analytical methods utilized in this study for on-site monitoring, sample collection and testing of the quality of the feed water, concentrated halogen stream and halogen-treated water at the disinfection contactor influent and effluent are described below. Use of either bench-top or in-line analytical equipment will be acceptable for the verification testing; however, in-line equipment is recommended for ease of operation. Use of in-line equipment is also preferable because it reduces the introduction of error and the variability to analytical results generated by inconsistent sampling techniques.

10.4.1 pH

Analyses for pH shall be performed according to *Standard Method* 4500-H+ or EPA Method 150.1/150.2. A three-point calibration of the pH meter used in this study shall be performed once a day when the instrument is in use. Certified pH buffers in the expected range shall be used. The pH probe shall be stored in the appropriate solution, as defined in the instrument manual. Transport of carbon dioxide across the air-water interface can confound pH measurement in poorly buffered waters. If this is a problem, measurement of pH in a confined vessel is recommended to minimize the effects of carbon dioxide loss to the atmosphere.

10.4.2 Temperature

Readings for temperature shall be conducted in accordance with *Standard Methods* 2550. Raw water temperatures shall be obtained at least once daily. The thermometer shall have a scale marked for every $0.1^{o}C$, as a minimum, and should be calibrated weekly against a precision thermometer certified by the National Institute of Standards and Technology (NIST). (A thermometer having a range of $-1^{o}C$ to $+51^{o}C$, subdivided in 0.1^{o} increments, would be appropriate for this work.)

10.4.3 True Color

True color shall be measured with a spectrophotometer at 455 nm, using an adaptation of the *Standard Methods* 2120 procedure. Samples shall be collected in clean plastic or glass bottles and analyzed as soon after collection as possible. If samples cannot be analyzed immediately they shall be stored at 4^{o}C for up to 24 hours, and then warmed to room temperature before analysis. The filtration system described in *Standard Methods* 2120 C shall be used, and results should be expressed in terms of PtCo color units.

10.4.4 Turbidity Analysis

Turbidity analyses shall be performed according to *Standard Methods* 2130 or EPA Method 180.1 with either a bench-top or in-line turbidimeter. In-line turbidimeters shall be used for measurement of turbidity in the filtrate waters, and either an in-line or bench-top turbidimeter may be used for measurement of the feedwater

During each verification testing period, the bench-top and in-line turbidimeters will be left on continuously. Once each turbidity measurement is complete, the unit will be switched back to its lowest setting. All glassware used for turbidity measurements will be cleaned and handled using lint-free tissues to prevent scratching. Sample vials will be stored inverted to prevent deposits from forming on the bottom surface of the cell.

The Field Testing Organization shall be required to document any problems experienced with the monitoring turbidity instruments, and shall also be required to document any subsequent modifications or enhancements made to monitoring instruments.

10.4.4.1 Bench-top Turbidimeters. Grab samples shall be analyzed using a bench-top turbidimeter. Readings from this instrument will serve as reference measurements throughout the study. The bench-top turbidimeter shall be calibrated within the expected range of sample measurements at the beginning of equipment operation and on a weekly basis using primary turbidity standards of 0.1, 0.5, and 3.0 NTU. Secondary turbidity standards shall be obtained and checked against the primary standards. Secondary standards shall be used on a daily basis to verify calibration of the turbidimeter and to recalibrate when more than one turbidity range is used.

The method for collecting grab samples will consist of running a slow, steady stream from the sample tap, triple-rinsing a dedicated sample beaker in this stream, allowing the sample to flow down the side of the beaker to minimize bubble entrainment, double-rinsing the sample vial with the sample, carefully pouring from the beaker down the side of the sample vial, wiping the sample vial clean, inserting the sample vial into the turbidimeter, and recording the measured turbidity.

For the case of cold water samples that cause the vial to fog preventing accurate readings, the vial shall be allowed to warm up by partial submersion into a warm water bath for approximately 30 seconds.

10.4.4.2 In-line Turbidimeters. In-line turbidimeters are required for treated water monitoring during verification testing and must be calibrated and maintained as specified in the manufacturer's operation and maintenance manual. It will be necessary to verify the in-line readings using a bench-top turbidimeter at least daily; although the mechanism of analysis is not identical between the two instruments the readings should be comparable. Should these readings suggest inaccurate readings then all in-line turbidimeters should be recalibrated. In addition to calibration, periodic cleaning of the lens should be conducted, using lint-free paper, to prevent any particle or microbiological build-up that could produce inaccurate readings. Periodic verification of the sample flow rate should also be performed using a volumetric measurement. Instrument bulbs should be replaced on an as-needed basis. It should also be verified that the LED readout matches the data recorded on the data acquisition system, if the latter is employed.

10.4.5 Chlorine Residual

Because free chlorine in aqueous solutions is unstable, the free chlorine concentration in treated water samples will decrease rapidly. Exposure to sunlight or other strong light, or agitation, will accelerate free chlorine loss. Therefore, analysis of free and total chlorine samples shall begin immediately after sampling, and excessive light and agitation shall be avoided. Samples to be analyzed for free or total chlorine shall not be stored prior to analysis.

Glassware to be used for chlorine analyses shall be chlorine demand free. Chlorine demand free glassware will be prepared by soaking glassware in a 50 mg/L chlorine bath for a period of 24 hours. At the end of this time, all glassware will be rinsed three times with organic-free water that has a TOC concentration of less than 0.2 mg/L. Glassware will then be dried at room temperature for a period of 24 hours. During the drying process, bottle openings will be covered with aluminum foil to prevent contamination.

The method for collecting samples for chlorine analyses shall consist of the following procedure: running a slow, steady stream from the sample tap, triple-rinsing a chlorine demand free sample beaker in this stream, allowing the sample to flow down the side of the beaker to minimize agitation, performing the free and total chlorine analyses, and recording the measured chlorine concentrations.

10.4.6 Iodine Residual

Because iodine provides a more stable residual than chlorine and is less affected by environmental factors, glassware used for sampling is not required to be iodine demand free. Analysis of iodine samples shall begin as soon as possible after sampling. Samples to be analyzed for iodine shall not be stored prior to analysis. The method for collecting samples for iodine analysis shall be the same as that described above for chlorine residual, with the exceptions noted herein.

10.4.7 Chlorine Dioxide Residual

Similar to chlorine, chlorine dioxide in aqueous solutions is unstable. Exposure to sunlight or other strong light, or agitation, will accelerate chlorine dioxide loss. Therefore, analysis of chlorine dioxide samples shall begin immediately after sampling,

and excessive light and agitation shall be avoided. Samples to be analyzed for chlorine dioxide shall not be stored prior to analysis. Glassware for chlorine dioxide analyses shall be chlorine demand free, as described above in Section 10.4.5. The method for collecting samples for chlorine dioxide residual shall be identical to that described above for chlorine residual.

10.4.8 Bromine Residual

Bromine in aqueous solutions is even more unstable than chlorine. Exposure to sunlight or other strong light, or agitation, will accelerate bromine loss. Therefore, analysis of bromine samples shall begin immediately after sampling, and excessive light and agitation shall be avoided. Samples to be analyzed for bromine shall not be stored prior to analysis. Glassware for bromine analyses shall be chlorine demand free, as described above in Section 10.4.5. The method for collecting samples for bromine residual shall be identical to that described above for chlorine residual.

10.5 Chemical and Biological Samples Shipped Off-Site for Analyses

The analytical methods that shall be used during testing for chemical and biological samples that are shipped off-site for analyses are described in this section.

10.5.1 Organic Samples

Samples for analysis of total organic carbon (TOC) and UV_{254} absorbance shall be collected in glass bottles supplied by the state-certified or third party- or EPA-accredited laboratory and shipped at 4°C to the analytical laboratory. These samples shall be preserved, held and shipped in accordance with *Standard Method* 5010 B. Storage time before analysis shall be minimized, according to *Standard Methods*.

10.5.2 Microbial Samples: TC and HPC Bacteria, Other Bacteria, Viruses and Protozoa

Samples for analysis of any microbial parameter shall be collected in bottles supplied by the analytical laboratory. Microbiological samples shall be refrigerated at approximately 2 to 8°C immediately upon collection. Such samples shall be shipped in a cooler and maintained at a temperature of approximately 2°C to 8°C during shipment. Samples shall be processed for analysis by the selected laboratory within 24 hours of collection. The laboratory shall keep the samples at approximately 2°C to 8°C until initiation of processing. TC densities shall be reported as most probable number per 100 mL (MPN/100 mL) and HPC densities shall be reported as colony forming units per mL (cfu/mL).

Methods for assessing the viability of the selected bacteria and viruses (see Table 6) shall be specified by the laboratory(ies) performing the analysis and shall be specified in the PSTP. The FTO may select a laboratory that is certified, accredited or approved by the state, a third party organization (i.e., NSF) or the USEPA for analysis of microbial contaminants in water samples.

Methods for assessing the viability of cysts and oocysts are non-standard but may be used in verifying objectives that an on-site halogen generation system inactivates protozoan cysts and oocysts if the method has undergone peer review. A summary and comparison of viability methods is presented in research completed by the following researchers: Korich et al. (1993), Nieminski and Ongerth (1995), Slifko et al. (1997) and others (see Section 12.0 References in this Test Plan). Any non-standard method for assessing cyst and oocyst viability shall be correlated to animal infectivity.

10.5.3 Inorganic Samples

Inorganic chemical samples, including alkalinity, iron, sodium, and manganese, shall be collected and preserved in accordance with *Standard Method* 3010B, paying particular attention to the sources of contamination as outlined in *Standard Methods* 3010C. The samples shall be refrigerated at approximately 4°C immediately upon collection, shipped in a cooler, and maintained at a temperature of approximately 4°C during shipment. Samples shall be processed for analysis by a state-certified or third party- or EPA-accredited laboratory within 24 hours of collection. The laboratory shall keep the samples at approximately 4°C until initiation of analysis.

10.5.4 Bromate

Samples for the analysis of bromate shall be collected in sampling containers supplied by the state-certified or third party- or EPA-accredited laboratory. Sample collection and storage requirements are outlined in EPA Method 300.1 or shall be provided by the laboratory conducting the analysis.

10.6 DBP Formation Test Protocol

The DBP formation test simulates full-scale disinfection by spiking a water sample with a disinfectant and holding the spiked sample in the dark at a designated temperature and contact time. The spiked water sample may be held at the uniform formation conditions (UFC) specified by the ICR Manual for Bench- and Pilot-Scale Treatment Studies as follows:

- Incubation period of 24 ± 1 hours
- Incubation temperature of 20 ± 1.0°C
- Buffered pH of 8.0 ± 0.2
- 24-hour chlorine residual of 1.0 ± 0.4 mg/L.

For this testing, one of two approaches may be employed, whichever is applicable:

1. If no additional dosing of halogens is used for residual disinfection subsequent to primary disinfection, the DBP formation test method shall be performed by collecting a sample of the treated water and holding the sample in the dark at the UFC.
2. If additional dosing of halogens is used for residual disinfection subsequent to primary disinfection, the DBP formation test method shall be performed by collecting a treated water sample, spiking it with an additional dose of disinfectant, and holding the sample in the dark at the UFC.

For either of the above approaches, as an alternative to utilizing the UFC, the conditions selected for DBP formation testing may be those that most closely approximate the residence time,

disinfectant type and disinfectant residual found in the distribution system at the location of the Verification Testing. These conditions shall be specified in the PSTP for approval by NSF.

For each DBP formation sample, three incubation bottles shall be set up. At the end of the incubation period, each sample shall be analyzed for the final disinfectant residual and the sample with the residual closest to the 1.0 ± 0.4 mg/L range shall be used for the specified DBP analyses.

All glassware used for preparation of the samples and reagents shall be chlorine demand free, as described above in Section 10.4.3.

The preparation of reagents and measurement of samples shall proceed as follows:

Preparation of Chlorine Stock Solution: The stock solution shall be prepared by adding an estimated volume of 6% reagent-grade NaOCl into a 500-mL, chlorine demand free bottle containing an estimated amount of organic-free water. To minimize the dilution error, the chlorine stock solution shall be at least 50 times stronger than the chlorine dose required.

Preparation of Other Halogen Disinfectant Stock Solution: For a halogen disinfectant other than chlorine, stock solution preparation shall be similar to that described above for chlorine stock solution. Organic free water shall be used for dilution and the stock solution shall be at least 50 times stronger than the halogen dose required.

Preparation of Additional Chemicals: Refer to *Standard Method* 4500-Cl F for the preparation method of DPD indicator, FAS standard and buffer solution.

Sample Collection and Incubation: The samples shall be collected in one liter amber bottles with Teflon lined caps. These bottles shall be stored in a temperature-controlled incubator at the specified temperature. Samples shall be adjusted to pH 8.0 ± 0.2 using 1 M HCl or NaOH and shall then be dosed with the appropriate dosage of chlorine (or other halogen disinfectant) to yield a chlorine (or other halogen disinfectant) residual of 1.0 ± 0.4 mg/L after the specified 24-hour storage period. The samples shall be capped head-space free and stored for 24 hours in the dark at the appropriate incubation temperature.

10.7 Health and Safety Measures

The FTO shall include in the PSTP specific instructions and description of the procedures that shall be used to ensure safe start-up, operation, sanitization and cleaning of the on-site halogen generation equipment during Verification Testing. In addition, the PSTP shall include information appropriate for inclusion in a Safety Plan. For example, a safety plan addressing health and safety measures shall address required actions in the event of equipment leaks, recommended organism handling procedures, requirements for protective personal equipment and bio-hazard signs etc. In summary, the following safety concerns shall be addressed by the FTO in the QA/QC plan applicable for the on-site generation equipment and verification testing procedures:

- Storage, handling and disposal of hazardous waste stream and chemicals including acids, bases, brine solutions, and oxidizing agents
- Storage, handling and disposal of biological waste streams

- Conformance with electrical code
- Chemical hazards and biohazards
- Need for spark-proof wires and/or National Electrical Code explosion-proof wiring
- Potential presence of explosive gases
- Ventilation of equipment, trailers (as applicable), or buildings (as applicable) if gases or chemicals generated by the equipment could present a safety hazard
- Emergency response procedures in case of equipment leaks or spillage of biological materials
- Requirement for personal protective equipment and emergency safety equipment.

11.0 OPERATION AND MAINTENANCE

The field testing organization shall obtain the Manufacturer-supplied O&M manual to evaluate the instructions and procedures for their applicability during the verification testing period. The following are recommendations for criteria to be included in Operation and Maintenance (O&M) Manuals for equipment for on-site generation of halogen disinfectants for inactivation of microbiological contaminants. The FTO will report on the applicability of the manual in the development of a final report of the Verification Testing period.

11.1 Maintenance

The Manufacturer shall provide readily understood information on the recommended or required maintenance schedule for each piece of operating equipment such as:

- pumps
- valves
- pressure gauges
- flow meters
- air compressors
- gas pressure vessels
- chemical feeder systems
- mixers
- motors
- instruments, such as turbidimeters, pH meters, halogen residual monitors
- water meters, if provided

The Manufacturer should provide readily understood information on the recommended or required maintenance for non-mechanical or non-electrical equipment such as:

- tanks and basins
- in-line static mixers
- tubing and hoses

11.2 Operation

The Manufacturer should provide readily interpretable recommendations for procedures related to proper operation of the equipment. In addition, the Manufacturer shall provide a schematic diagram that indicates the flow path of raw water, wastewater and disinfectant chemicals. Among the operating aspects that should be discussed are the following issues:

Disinfectant/Halogen Generation:
- control of feed flow to the on-site halogen generation system
- measurement of halogen concentration generated at a selected percent system output
- measurement of gas pressures (where applicable) generated during halogen generation during on-site system operation
- change in feed flow and halogen generation in response to temperature changes

Disinfectant Contact Time:
- control of feed flow to disinfectant contact basin
- adjustment of hydraulic detention time (i.e., volume if appropriate) in the contact basin
- control of halogen concentration dosed to the contact basin

Chemical Feeders (in the case that chemical pretreatment is applied):
- chemical feed pumps calibration check
- settings and adjustments -- how they should be made
- proper procedures for dilution of chemicals

Intermittent Operation:
- proper procedures for system shut-down and start-up of on-site generation system
- safety checks of halogen and gas concentrations prior to system shut-down
- safety checks of potential microbiological contaminant concentrations prior to system shut-down and start-up
- proper procedures for rinsing and disinfection of system following shut-down
- proper procedures for disinfection of system following spiking of microbiological contaminants

Monitoring and Sampling Procedures:
- observation of feed water quality or pretreated water turbidity
- observation of halogen generation efficiency as a function of feed water quality, flow rates and generation system output
- proper sampling procedures for spiking of microbiological contaminants
- proper safety and disinfection procedures following spiking with microbiological contaminants

The Manufacturer should provide a troubleshooting guide; a simple check-list of what to do for a variety of problems including:
- no raw water (feed water) flow to plant
- lack of feed water flow control through equipment
- valving configuration for direct feed flow and pretreated feed flow to system
- poor filtrate quality
- failed halogen generation safety test
- low pump feed pressure
- automatic operation (if provided) not functioning
- reduced rate of halogen generation at same percent system output
- machine will not start and “Power On” indicator off
- machine will not start and “Power On” indicator on
- pump cavitation

- valve stuck or won't operate
- no electric power
- no chemical feed
- no chemical feed to halogen generation system

11.3 Operability

The following are recommendations regarding operability aspects of systems that are designed to achieve inactivation of microbiological contaminants. These aspects of plant operation should be included if possible in reviews of historical data, and should be included to the extent practical in reports of equipment testing when the testing is done under the ETV Program.

During Verification Testing and during compilation of historical equipment operating data, attention shall be given to equipment operability aspects. Among the factors that should be considered are:

- Fluctuation of flow rates, halogen generation and pressures through unit, as well as the time interval at which flow control and adjustment of halogen production is needed
  - ⇒ Does on-site generation system (and any contact tanks provided) provide for variable hydraulic detention time and contact with disinfectant?
  - ⇒ How long can feed pumps and halogen generation equipment maintain target flow and contact time values?
  - ⇒ Is rate of feed water flow to on-site generation system measured?
  - ⇒ Does plant have facilities for pretreatment of feed water in the form of the following: pH adjustment, coagulant chemical feed, other?
  - ⇒ Can pretreatment chemical dosing (if applicable) be adjusted with changes in feed water flow?
- Presence of devices to aid the operator with adjustment of flow control, halogen generation, chemical dosage selection and system safety
  - ⇒ does rate of primary chemical feed change with flow of feed water or change in feed water quality (e.g., halogen demand)?
  - ⇒ are on-line halogen concentration monitors provided with on-site generation system?
  - ⇒ does remote notification to operator occur when a failure of on-site generation system occurs?
- Provision of on-line water quality monitors for feed water, concentrated halogen stream and halogen-treated water streams at the disinfection contactor influent and effluent
  - ⇒ are on-line turbidimeters provided on feed water stream?
  - ⇒ are on-line halogen residual monitors (e.g., chlorine monitors) provided on the halogen-treated water streams?

Both the reviews of historical data and the reports on Verification Testing should address the above questions in the written reports. The issues of operability and production should be dealt with in the portion of the reports that are written in response to Task 1 of the Verification Testing Plan.

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